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Limitations to the Use of Employee Exposure Data on Air Contaminants in Epidemiologic Studies

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Summary. The bias in the estimation of uptake of substances in the human body from exposure data gathered from ordinary workplace check-ups is discussed. It is concluded that most exposure is probably overrated. This means that exposure limits based on these premises will tend to be too high. To counteract this bias in the future, filed exposure data should be accompanied with information on a number of circumstances which prevailed at the sampling.

Key words: Bias – Exposure data – Air contaminants – Work sites – Permissible exposure limits

Introduction

The purpose of an epidemiologic investigation is to establish a causal association between categories of events occurring in a group of persons: one category being, for example a disease in a certain proportion of the group and another category being an attribute or experience in a certain proportion of the group [21]. This attribute or experience in occupational health will often be an exposure to a known chemical or physical factor. The definition of noneffect levels of these factors or even the substantiation of dose-response or dose-effect relationships is of special interest for the purpose of setting or revising exposure limits [16]. This ambition as goal unfortunately is often hampered by the inadequacy of exposure data.

The concept of exposure of an employee to a substance in the work environment may denote at least two things. It may indicate the dose of the substance absorbed in the body. It may also merely indicate the presence of the employee in an environment in which there is a more or less well determined concentration of the substance, from which an uptake of the substance is deduced. The purpose of the following inquiry is to discuss the bias in the estimated uptake. Random error in concentration determinations, although important as such, is considered only briefly in this context.

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Exposure measurements may be performed either in order to check if the environment complies with exposure limits or, at least in theory, in order to estimate the uptake of a substance for the purpose of epidemiologic studies. It is important to separate these two goals, since the outcome of measurements with one or the other purpose will be quite different.

Most epidemiologic studies are retrospective. If a prospective investigation is considered, it is probably also justified to control the exposure, which will entirely change the premises of the investigation [16]. Consequently most epidemiologic studies are reduced to using data from measurements already made, and made for other purposes. Hence it is important to judge the relevance of the few data which may be found in the best possible way. The following factors and circumstances may affect the bias of estimated uptake deduced from exposure data: (a) the intention of the measurement, (b) the methods used and (c) the investigation strategy. These factors affect the representativeness of the exposure data. Additional factors affecting the uptake but not the concentration of contaminants in the air must also be considered. Such factors are (d) part-time exposure, (e) the use of respirators, (f) personnel rotation, (g) unfavourable distribution of exposure periods over time and (h) unusually hard work increasing the ventilation of the exposed individual.

2. Methods

2.1 Sampling of Air Contaminants

The measurement of exposure to air contaminants may be performed by analysing their concentration and variation with time in the inhaled air of the exposed employee. This can be accomplished by sampling close to the nose of the employee. This has been a regular practice since the introduction of portable equipment including battery driven pumps in 1960 [25]. It is also possible to estimate exposure from data on the concentrations in various places or "zones" where the employee is present [10] or from exposure data with regard to various occupational titles or uniform task classes to which the employee belongs [11, 12, 32].

2.2 Investigation Strategies

The purpose of this section is to list and describe sampling strategies which are in current use or may have been used in the past.

2.2.1 No Visits "Startegy". When no visits at all are made to a work place, this "strategy" may be a well founded choice or due to lack of resources, or even ignorance.

2.2.2 Inspection. At its best an inspection is a qualified evaluation based upon surveying a place of work and a work operation, possibly combined with inference from earlier measurements at the same place of work or what are supposed to be similar places of work. Actual measurements may occasionally be performed at the inspection, e.g. by detection tubes or other direct reading instruments. When notations have been made regarding reactions to the environment, e.g. smell of a substance or acute reactions of the employees as irritation, lachrymation or even fainting, conclusions as to the level of exposure may be drawn. The few data generated in an inspection are unlikely to be representative. The samples may refer to the general work room atmosphere or to the "worst case" without any reference in the records.

2.2.3 Identification. This indicates sampling and analysis with the purpose of identifying unknown substances in the air. The samples may be taken, e.g. by a "high volume sampler" in a suitable position of the premises investigated or by other means depending on how the

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determinations are to be performed. Identification of unknown substances are meant to be just qualitative and any noted concentrations are not likely to represent normal conditions. The desire to collect enough material for a determination will probably lead to a positive bias, in such data.

2.2.4 Finding "Worst Cases". Random samples (grab samples) are taken during minutes or longer periods depending on the sensitivity of the analytical methods in the vicinity of operations and during phases of operations where high exposure is expected. The purpose is to get a measurement relevant to the "worst possible case" and also to check compliance with ceiling standards. "Whorst cases" are by definition not representative. If the results are applied to other groups within the same industry, the bias will be positive.

2.2.5 Monitoring of Time Weighted Average Concentrations. The goal is to measure the daily average exposure of selected employees during normal production and to check compliance with exposure limits [28]. The samples may be taken as a number of short-period samples at random during a day or as full period samples [19,28]. If data are applied to other groups of employees, the bias may be positive or negative depending on how the selection was made.

2.2.6 Work Area Sampling. This may indicate static sampling in the work area in order to investigate the background concentration of the air contaminant there with no particular regard to the exact position of the employees in the localities. Such sampling will in itself not reveal exposure. The level of exposure has to be derived from other data as well. These data may be incomplete or entirely lacking. Since the occupational hygienist may be inclined to sample where he can get high results, while the employees avoid "hot spots" if they can, the bias may be positive.

Work area sampling may also indicate static sampling made with regard to positions of employees where an average concentration is likely. In this case, much random error in estimating individual exposure is likely, but not essentially biased.

2.2.7 Emission Measurement. Measurement of the emission (weight unit of contaminants per time unit) from different sources of contamination is applied in a few instances. Emission measurements say nothing about the exposure. The calculations involved in order to derive the exposure are based on several very uncertian factors, e.g. production, ventilation, air movements, and positions of employees in the localities.

2.2.8 Biological Sampling. When sampling and analysis of e.g. blood or urine from exposed employees is applicable, they are supposed to reflect uptake in individuals or groups in the best possible way. The relationship to exposure in the environment varies with the substance in a complicated way, however. Samples may be taken when a dangerous exposure is expected, but it is also possible that all employees of a certain trade are examined on a routine basis.

Strategy no. 2, sometimes combined with no. 3, may form the introductory phase of a planned larger exposure monitoring program. The most common of the strategies is no. 1 and then nos. 4, 5 and 8. Strategies nos. 4 and 5 may be applied separately or combined. The importance of strategy no. 6 has decreased since portable sampling equipment has been introduced, but it is still used in connection with the planning and checking up of control measures. Strategy no. 7 is unusual, especially since it is difficult to arrange for emission measurements in the normal operations of a factors. A hybrid between emission and immission measurements has been practised in a study of welders [31].

2.3 Compliance Testing

Compliance with exposure limits may be tested in different ways. While Leidel et al. [19] advocate a very precise statistically based compliance testing, others prefer qualitative reasoning, e.g. the Swedish authorities [8]. Most suggested procedures are derived from the following models.

2.3.1 Conventional Procedure. Compliance exists when the time weighted arithmetic mean is below the exposure limit. Excesses above the limit are permitted within short-term exposure

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limits [6, 8]. The short-term exposure limits will function as a limit to the acceptable range in readings when the mean is close to the exposure limit and thus limit the chance of false statements of compliance.

2.3.2 Testing of Statistical Hypothesis, Comparison with the Confidence Limits. The normal or log-normal distribution model is used to calculate the upper and lower confidence limits of the mean at some reasonable confidence level. It is suggested that the lower confidence limit be used primarily by the compliance officer to test possible noncompliance with exposure limits and that the upper confidence limit be used primarily by the employer to test possible compliance with exposure limits[19]. A shortcoming of this procedure is that the range in readings is not controlled. Therefore the power of the test should also be considered [28].

2.3.3 Overexposure Risk. The risk of overexposure on any occasion when the apparant exposure on that occasion is in compliance with the exposure limit has been calculated considering various premises [20]. It is suggested that an "action level" of half the exposure limit be used.

2.4 Decision Models

It is a fact that the eagerness with which exposure limits have been enforced has varied considerably with time and from one nation to another, as it depends among other things on the legal status of the exposure limits. The consequences of noncompliance with exposure limits therefore have been very different in different situations in the past. The decisions critical to the bias of old exposure data regard the possibility of repeating measurements and the control measures taken. If effective control measures result from a decision of noncompliance with exposure limits, the old exposure data will rapidly be rendered obsolete. If applied to future situations they will be positively biased. If measurements are repeated only when high concentrations are registered and further measurements cancelled when a single low reading is observed, negative bias is inevitable.

A detailed decisions scheme has been developed for the National Institute of Occupational Safety and Health [19]. When the exposure limit has been exceeded, the person is informed about it and control measures taken. Then new measurements are performed at regular intervals until repeated results show concentrations below the "action level". When the "action level", but not the exposure limit, is exceeded measurements are performed at regular intervals until repeated results show concentrations below the "action level". If this program is enforced the influence of chance in measurements and decisions will be minimized. The data generated will probably be representative for most exposed employees on the premises. Important to the usefulness of exposure data are also the decisions taken when random samples are far below the exposure limit. In most cases all further measurements will be cancelled when concentrations are well below the exposure limit and the number of data in such situations therefore will be very limited.

3. General Representativeness of Exposure Measurements

3.1 Distribution of Concentrations of Air Contaminants

Concentrations of samples of contaminated air usually have positively skewed distributions. It is now rather generally acknowledged that these distributions are approximately log-normal [19, 28], i.e. the logarithms of the concentrations are normally distributed [2]. As an example, the general agreement with the log-normal distribution of a large amount of concentration data in connection with welding has been confirmed [31].

The relative positions of the mean, median (= geometric mean) and mode (= most frequent value) at $e^{\mu + 1.2\sigma^2}$, e^{μ} and $e^{\mu - \sigma^2}$ (μ and σ being the mean and

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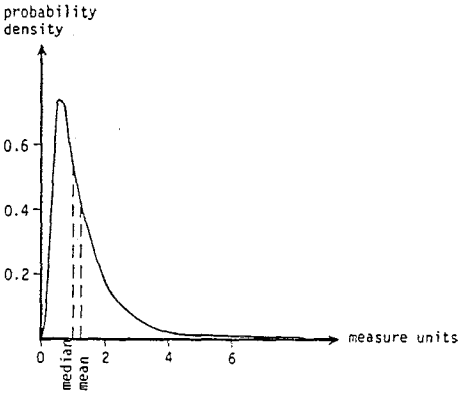

Fig. 1. Relative positions of arithmetic mean and median in the log-normal distribution

Table 1. The area on the left of the arithmetic mean under frequency curves of log-normal distributions with varying geometric standard deviation

GSD	Area
1.5	0.58
2	0.64
2.5	0.68
3	0.71
3.5	0.73
4	0.76

standard deviation of the logarithms of the variate) emphasize the positive skewness of the distribution, cf. Fig. 1. Some authors also refer to the geometric standard deviation, GSD $= e^{\sigma}$ [19, 20]. A simple relation obtains between the quantiles of the log-normal distribution and the corresponding quantiles of a normal distribution with mean = 0 and standard deviation = 1. If v_q is the quantile of order q of the normal distribution then the $q:th$ quantile of the log-normal distribution will be $e^{\mu + v_q \cdot \sigma}$.

The skewness of distributions of air contaminant concentrations found in industrial operations has been investigated by Leidel et al. [20]. Also, quoting other authors, they conclude that the median category of GSD's of particulate sampling data from a great number of measurements in various branches was 1.60 to 1.69 and the median category GSD's of gas and vapour sampling data 1.50 to 1.59 [20].

The difference in intra- and interindividual variations may be exemplified with the dust exposure of 63 welders performing shielded electric arc welding on stainless steel [30]. Dust was sampled inside their face guards in the morning and in the afternoon. The GSD within days (same welder) was 1.2 and between welders 1.6 on the average.

An illustration of the consequences of the skewness is given in Table 1 giving the relative frequencies with which log-normal distributed observations will fall below the arithmetic mean when the GSD varies. If the distribution is normal

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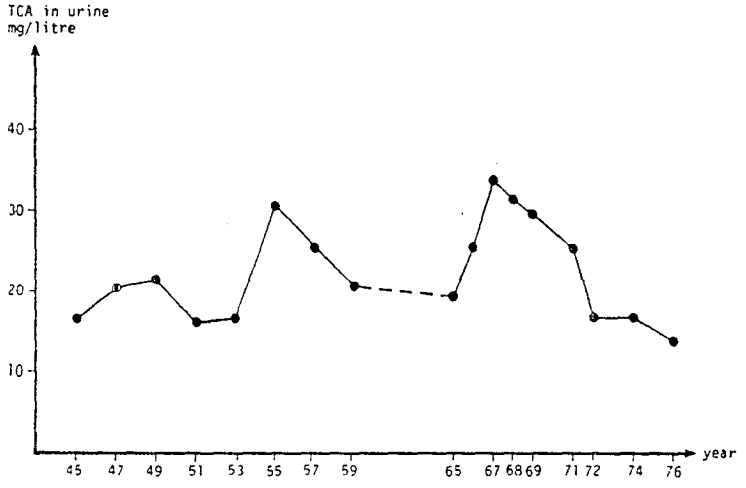

Fig. 2. Yearly geometric means of TCA in urine samples taken in health controls on employees exposed to trichlorethylene in Sweden 1945–1976

this frequency by definition is 50%. When the skewness increase the relative frequency of observations below the arithmetic mean increases, e.g. there is more than a 70% chance in random sampling of observing a single variate less than the arithmetic mean when the geometric standard deviation is 3, a high but not unusually high spread. Only if a number of observations are made, will the mean converge with the true overall mean. The importance of the arithmetic mean is obvious considering that, in full period sampling, the arithmetic mean of the period is automatically registered and that in principle the accumulated uptake of the human body is proportional to the arithmetic mean of the period under observation. This will be further discussed below.

3.2 Variations in Exposure over Long Periods

In Sweden and other industrialized countries there has been a general trend towards lower employee exposure to air contaminants in the work environment at least during the 1970's, as indicated by the continuous revisions of the exposure limits. The trend is shown in those cases where long-term series of incidences of occupational diseases or exposure measurements are available as reported for silicosis and quartz exposure [1]. As a measure of exposure to trichloroethylene, trichloroacetic acid (TCA) has been determined in urine for a long time [3]. Each year since the 1940's, hundreds of urine samples have been sent to the National Institute of Public Health, later the Institute of Occupational Health, in Sweden for analysis of TCA. The yearly geometric means of these analyses are plotted in the Fig. 2. The curve indicates a general long-term increase in the exposures on to the end of the 1960's and then a significant decrease. The yearly means of the concentrations of lead in blood samples taken in health controls in Finland during a number of years has been reported [17]. From 1969 on to 1976 there has been a steady and substantial decrease.

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Table 2. Investigations in a number of representative paints factories in 1976 and 1979. Range of the sum of concentrations of solvents, each standardized with the corresponding permissible exposure limit value in common operations before and after an extensive cleaning-up program [4, 26, 29]

Operation	Before control (1976)	After control (1979)
Charging of raw materials	0.02–16.0	0.15– 0.54
Pigment dispersion	0.2 – 4.4	0.43– 0.78
Tinting	0.1 – 2.0	0.3 – 2.4
Filling of cans	0.02– 6.6	0.12– 1.1
Cleaning of equipment with solvents	0.5 –30.0	0.33–47.0

It is obvious that a lot of changes habe been imposed on the individual factory, e.g. as a result of measures taken to limit exposure or as a consequence of changes in the production. It is necessary to have accurate knowledge of the investigated factory or branch if exposure data is to be correctly interpreted. As an example, two surveys in the paint industry in 1976 and 1979 [4, 26, 29] are presented in the Table 2. Between these two years large-scale cleaning up operations were in progress in the whole branch. As a result the exposure to solvents decreased considerably in several types of operations. The group of persons occupied with the solvent cleaning of equipment, who were the worst exposed employees, showed no change in their conditions, however.

The conclusions of these examples is that if exposure data are generalized over a long period of time, the estimated uptake of substances will probably be considerably in error. The sign of this bias will vary depending on the long-term development of the exposure to the substance in particular and how the generalization is made.

3.3 Variations in Exposure with the Time of the Year

When there is a season effect on exposure this must obviously affect the inference from measurements during one season to other seasons. An example of effects due to the time of the year is given in the Fig. 3, showing the exposure of welders to welding fumes. Welding the same material and with the same method is performed in a rather similar way irrespective of where it is done [31]. In the figure geometric means of exposure of different welders in different enterprises working with three independent methods have been plotted against the month of the year in which the measurements were made. The differences are significant according to analyses of variance performed with the logarithms of the concentrations. A second example is given in the Fig. 4. Monthly geometric means of TCA concentrations in urine samples mentioned above show a significant seasonal effect on exposure.

An explanation of the season effect on the two entirely different exposure situations in the examples may be the changes in the general ventilation during a year. When the outdoor climate is mild in Sweden in May through August, the air exchange through windows and doors may be important, while there is a

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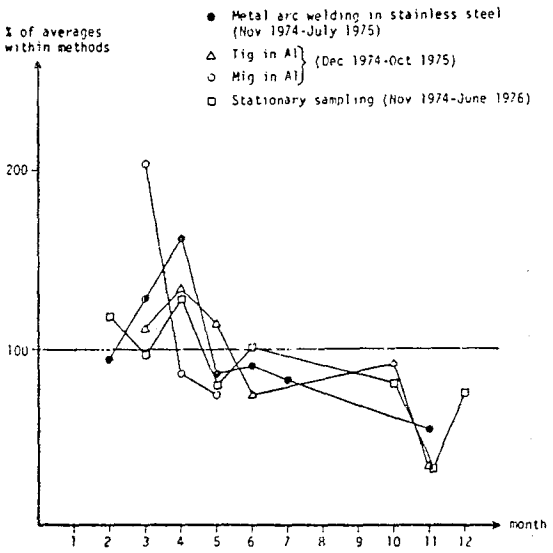

Fig. 3. The effect of the season. Geometric means of concentrations of welding fumes in the inspiration air of the welders inside the face guard and at stationary sampling places in the work rooms. The samples were taken in 40 enterprises 1974–1976. No local exhaust ventilation (spot ventilation) was used. The monthly geometric means of each method is given as percent of the grand geometric mean of the method, for metal arc welding in stainless steel 3.8 mg/m^3, for Tig in Al 1.1 mg/m^3, for Mig in Al 10.4 mg/m^3 and for the background in the work rooms 3.8 mg/m^3 l

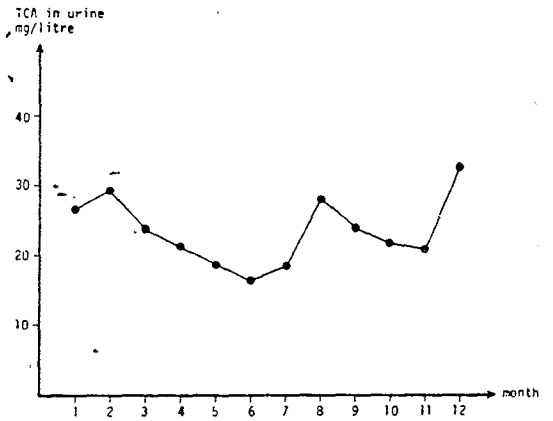

Fig. 4. The effect of the season. Geometric means of trichloracetic acid in urine taken in health controls on employees exposed to trichlorethylene in Sweden the years 1945, 1947, 1949, 1951, 1965, 1966, 1967, 1968 and 1969

tendency among employees to turn off the forced ventilation to avoid draught when outdoor temperatures are low in January through March. The variations between the days of the week is sometimes appreciable as observed e.g. in dry cleaning enterprises and metal industries where the exposure to trichloroethylene was at its peak in the middle of the week [3].

The situation with respect to work load in the industry may also influence the exposure. This situation follows a typical pattern over the year and should be considered for the particular branch under study. In the above example of exposure to dust in welding, the arc time factor was observed. There was no significant difference in different months in the arc time factor indicating that the work intensity did not cause the variation.

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3.4 Errors in the Determination of Samples of Air Contaminants

The magnitude of the errors in the determinations of samples made one or two decades ago are rarely stated. This is so partly because a statistical view on analytical results is a rather recent accomplishment, even today not universally accepted by all analytical chemists.

Nowadays it is common to provide descriptions of analytical methods with data regarding precision [5]. Coefficients of variation in repeated analyses with a number of frequently used methods operated by the same operator are reported in the range 5–10% [5, 10]. This is an overestimation of the precision in the determination, however, when different laboratories and different methods and instruments are used.

In a series of interlaboratory calibrations, samples containing predetermined quantities of quartz, asbestos fibers or organic solvents where determined [18]. The limit of acceptance of a laboratory was for quartz and asbestos about ± 30% from the predetermined value and for organic solvents ± 15%. The standard deviations and ranges in determinations of organic solvents are presented in the Table 3. This table shows that some laboratories make large errors, although fortunately this is rather rare.

The variation due to analysis is usually much less than the variation due to the sampling error at different times of e.g. the day. If a sample is taken e.g. in the inhaled air of an employee during one day and n determinations are made of the sample then the variance s^2 of the mean of the n determinations is composed of the variance s_1^2 in the true concentration of each sample and the variance s_2^2 in the determination of each sample: $s^2 = s_1^2 + s_2^2/n$ [14]. In most cases only 1 determination is made of a sample and the equation is reduced to $s^2 = s_1^2 + s_2^2$. Usually the estimation of s_2^2 has to be based on repeated measurements of a few samples.

It can be safely assumed that most methods of determination have coefficients of variation far below e.g. 30%. To exemplify the importance of a coefficient of variation of 30% in the analytical determination it is assumed that the GSD of the true concentration values in one case is 1.60. Then the total GSD due to variation in the concentrations and in the determination will be about 1.70. The conclusion is that low precision in the determinations (e.g. about 30%) is usually not a serious drawback. The possibility of a considerable systematic error is a more important threat to the relevance of exposure data. The chances are good that large systematic errors have not been introduced in present day determinations since the methods have improved greatly during the past decade.

3.5 Random Errors

It is a well known fact that if the values of the independent variable in e.g. a regression analysis are encumbered by random errors, the regression coefficient found will be smaller than the regression coefficient determined from values of the independent variable without errors [14]. Random errors in measuring an exposure variable therefore tends to bias the slope of an exposure response line towards zero [9]. In practice this effect is usually unimportant in comparison with other biases discussed here, even in those rare cases where enough data are available to make a regression analysis of exposure vs response.

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Table 3. Result of interlaboratory calibration [18]. Samples on charcoal tubes corresponding to 5 l of air with a concentration in the range 5 times the permissible limit to one-fifth of the limit. s = the standard deviation, r = the range (lowest and highest values)

Substance	Set 1			Set 2			Set 4			Set 5		
	Number of participating labs	s%	r%	Number of participating labs	s%	r%	Number of participating labs	s%	r%	Number of participating labs	s%	r%
Styrene	14	11	37–137	24	12	77–310	29	12	55–299	–	–	–
Tri	9	11	82–181	–	–	–	–	–	–	26	6	77–178
Xylene	13	11	31–134[a]	24	12	67–127	30	8	8–264	25	9	69–130

[a] One laboratory reported concentrations about 10 times too high

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4 Additional Factors Influencing Exposure to a Substrate

4.1 Part-time Exposure

It is rather unusual that an employee is occupied with a single operation during the whole workday or shift. As an example, in metal arc welding of nonalloy steel in workshops, the geometric mean of the arc time factor was 22% [31]. This applies for employees engaged full-time in welding, i.e. almost 80% of the time is used up for preparations before the welding or grinding, etc. after the welding.

Other causes of limited exposure which should be considered are the use of respirators and rotation of personnel, practised in e.g. the control of lead exposure in many countries [7]. If uptake is estimated from concentration data of air contaminants without considering limited exposure an appreciable positive bias will result.

4.2 Influence on Uptake of a Substance of Short-term Variations in Exposure

It is quite obvious that variations in concentrations of substances in the air within a day or shorter periods is important to the results. A single breath of air containing a very poisonous gas in a sufficiently high peak concentration may be fatal, although the average concentration of this gas over one day may be tolerable. This is an area of concern for accident prevention, however, and has very little to do with the monitoring of gases and vapours in order to check compliance with exposure limits.

In the simplest exposure model, response or effect is studied as a function of a single dose. This model of course is far from reality. A more complicated but still unrealistic model implies repeated doses of the same size. In reality the exposure will be composed of a complicated pattern of episodes with repeated doses of varying magnitude interrupted by breaks of varying lengths without exposure. Furthermore all exposed subjects in reality have an individual exposure pattern.

As has already been pointed out by Roach [23, 24], the durations of peak concentrations in relation to the biological half-life of the substance should be considered in judging exposure to air contaminants. The critical durations of peak concentrations and interruptions in the exposures are of the same magnitude as the biological half-life of the substance in the body. If the peak durations and the interruptions between peaks are much shorter than the biological half-life, the substance eventually will reach a concentration level in the body corresponding to the equilibrium at the average concentration in the air. If the durations of peaks are much longer than the biological half-life of the substance in the body, there will be enough time for the substance to accumulate to a concentration level in the body corresponding to the height of the peaks. The uptake will come into "resonance" with the environment, cf. Fig. 5, based on models suggested by others [13, 15, 22], further discussed in reference [27]. The implication of Fig. 5 is that although the average concentration is the same in the different exposure cases the uptake will be very different. It is possible that different organs in the body will respond differently to the exemplified exposure cases, e.g. one organ may respond to the area under the concentration-time curve, while a second organ may respond to the peak heights. Very little is known about this, but it is

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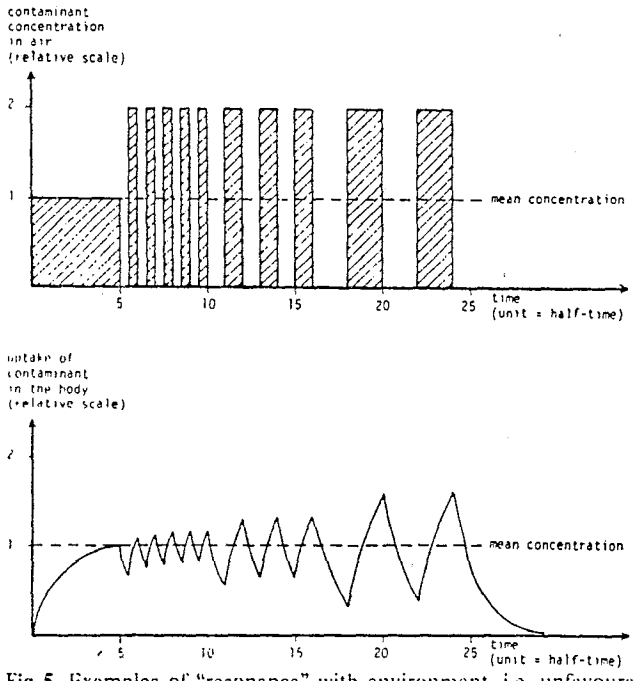

Fig. 5. Examples of "resonance" with environment, i.e. unfavourable exposure situations. Simple first order kinetic with main uptake and excretion via the lungs is assumed [22, 27]. In all exemplified exposure situations the average air concentration of the contaminant is the same (= 1 in the relative scale). The peaks of the body concentration will corresponded more and more closely to the peaks in the concentration in the air when the exposure episodes have a lenght at least as long as the biological half-life of the substance in the body observe that the diagrams should be read simultaneously and show what is assumed to happened at the same time in the inspiration air and the body!

suggested that when available data allow an investigation, the distribution of exposure over time should be considered. The possible bias is negative since the measured concentration is lower than the effective concentration during short periods.

5. Conclusions

Sampling strategies have been discussed almost exclusively with the view in mind of checking compliance with exposure limits or to some extent finding a basis for or checking control measures to decrease the exposure. Except for a few recent contributions [11, 12, 32] almost no efforts have been made to develop sampling strategies in order to describe the true uptake pattern of substances in the bodies of exposed employees and for obvious reasons: the ethical problem involved in prospective epidemiological studies [16] and the prohibitively high costs in making measurements when the future use of the measurements are uncertain.

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Table 4. Bias in the estimation of uptake of a substance in a group of employees when uptake is deduced uncritically from various sources of information. + = means that uptake is overrated, − = means that uptake is underrated in comparison with probable true uptake

	Premises of data	Cause of bias	Probable sign of bias	Validity of sign of bias
	Measurements and uptake in the same period and work place			
1)	Identification of the substance	Biased sampling in the locality to get above detection limit	+	2
2)	"Worst Case"	Biased sampling among employees	+	3
3)	Monitoring daily averages	Biased sampling among employees	+ or −	
4)	General work area sampling	Biased sampling in the locality to find "hot spots"	+	2
	Biologic sampling	Biased sampling among employees	+	1
	Unconditioned, regular check-ups	No additional bias	0	2
5)	No repeated measurement are made when the first result shows compliance	Biased sampling (the first result may have been unusually low)	−	2
6)	*Measurements and uptake in the same period and "similar" work place*	Biased sampling among enterprises	+	2
	Measurements and uptake in different periods of time			
7)	Measurements made in a period before uptake	Technical development	+	2
8)	Measurements made in a period after uptake	Technical development	−	2
9)	Measurements and uptake in different seasons	Regular variations	+ or −	
	Other circumstances			
10)	High exposure limit during measurements	Few data. Biased interpretation	−	1
11)	Rotation of employees to unexposed work	Invalidation of data	+	3
12)	Use of effective respirator	Invalidation of data	+	3
13)	Unfavourable exposure pattern	"Resonance" (cf. text)	−	2
14)	Hard physical labor	Increased lung ventilation	−	2

Code referring to the estimated validity of the suggested sign of bias:
3 = self evident; 2 = a conclusion with some reservation; 1 = an educated guess

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Table 5. The consequence of the sign of bias in measurements on the error in standard setting

Sign of bias	Interpretation	Effect on standard setting	Consequence
+	Observed conc. too high	Standart too high	"Health error"
−	Observed conc. too low	Standard too low	"Economic error"

To use the limited data available the investigator must have a reasonable idea of the sign of the bias in the estimated uptake. The bias may be due to a lack of representativeness or to additional circumstances, in the work situation. In Table 4 the probable bias of estimated uptake deduced from exposure data in an uncritical way is summarized. Some of the conclusions in Table 4 are self evident, others must be regarded more or less with reservations as discussed in some details in Section 2. The opinion of the author about the validity of the suggested signs of bias in Table 4 is expressed in the form of a code in the table. As has already been stated, if the exposure is overestimated the risk will be underestimated and vice versa. An inspection of the summaries of sings in the errors in Table 4 seems to suggest that overestimation of the uptake will be the most common outcome of judging the exposure from old data. The epidemiologist using old exposure data may use Table 4 as a checklist and try to find out the premises of his data and thus the most probable sign of bias. The implication of an overrated uptake is that exposure limits set will tend to be too high and the risk will be underrated ("health error"), cf. Table 5. It may be possible to some extent to counteract this simply by applying safer (=lower) exposure limits, but this may be possible only when the technical feasibility is obvious. In the long run there is no natural "safe side," since an exposure limit which is too low will cause unnecessary costs "economical error") affecting the possibilities of limiting more critical exposures. In the future, filed exposure data should be accompanied by all information necessary to judge their validity. The following factors should be considered.

(a) The name and nature of the operation(s) going on, products used and manufactured (declaration of content), contaminants formed.
(b) The average proportion of time used for the operation per day, week, year.
(c) Regular use of respirators, rotation of employees, notation of hard physical labour of the employees.
(d) Why, when, where and how the sampling was performed.
(e) Analytical method.
(f) Exposure limit at the time of sampling.

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